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Fatima Laggoun-Défarge[1], Daniel Gilbert[2], Alexandre Buttler[3], Daniel Epron[4], André-Jean Francez[5], Laurent Grasset[6], Christophe Guimbaud[7], Edward A. D. Mitchell[8], Jean-Claude Roy[9]

[1] Earth Science Institute, UMR 6113 CNRS – Univ. Orleans, France,
Tel: +33 238 49 46 63, fax: +33 238 41 73 08
E-mail: fatima.laggoun-defarge@univ-orleans.fr

[2] LBE, UsC INRA 3184 – Univ. Franche Comté, Montbéliard, France,
Tel: +33 381 99 46 95, fax: +33 381 66 57 9
E-mail: daniel.gilbert@univ-fcomte.fr

[3] UMR 6565, Besançon (F), WSL Restoration Ecology (CH) & EPFL, ECOS Lausanne (CH)
Tel: +41 21 693 39 39, fax: +41 21 693 39 13
E-mail: alexandre.buttler@epfl.ch

[4] EEF, UMR 1137 INRA – UHP Nancy, France.
Tel: +33 383 68 42 49, fax: +33 383 68 42 40
E-mail: daniel.epron@scbiol.uhp-nancy.fr

[5] ECOBIO UMR 6553 CNRS – Univ. Rennes, France,
Tel: +33 223 23 50 78, fax: +33 223 23 16 26,
E-mail: Andre-Jean.Francez@univ-rennes1.fr

[6] SRSN, UMR 6514 CNRS – Univ. Poitiers, France,
Tel: +33 549 45 37 59, fax: +33 549 45 35 01
E-mail: Laurent.Grasset@univ-poitiers.fr

[7] LPCE, UMR 6115 CNRS –Univ. Orléans, France,
Tel: +33 238 49 46 19, fax: +33 238 63 12 34,
E-mail: christophe.guimbaud@univ-orleans.fr

[8] WSL, Wetlands Research Group, (CH) & EPFL, ECOS, Lausanne (CH),
Tel: +41 21 693 57 50, fax: +41 21 693 39 13
E-mail: edward.mitchell@epfl.ch

[9] FEMTO-ST CREST, Univ. Franche Comté, Belfort, France,
Tel: +33 381 66 65 88, fax: +33 384 57 00 32
E-mail: jean-claude.roy@univ-fcomte.fr

Summary

Within the PEATWARM project, we use *Sphagnum* peatlands as a model to analyse their vulnerability to climate change using an experimental system (ITEX) that simulates *in situ* an increase in average temperature. We aim to determine the effects of temperature increase on the vegetation, the balance of above- and belowground gas fluxes (CO_2 and CH_4), the microbial diversity and activity in *Sphagnum* mosses and in peat, and the dynamics of labile and recalcitrant organic matter of peat. The ultimate objective is the creation of a biogeochemical model of C coupled with N and S cycles that includes interactions between these key compartments.

Key index words: Global warming, C, N, S cycles, ITEX manipulations, ecosystem structure and function, biogeochemical model of C.

Introduction

The debate on the effects of climate change on global stocks of carbon (C) in soils is front page news. Global warming induces complex interaction effects which could have a positive or a negative feedback on C storage in soils: it can induce the reduction of C stored belowground by accelerating the decomposition of organic matter (OM) and thus increasing atmospheric CO_2 concentrations, but it can also increase primary production and thus C inputs to soils. Peatlands are now recognised as valuable pools of sequestered C and their response to these potential predictive feedbacks on the global C cycle becomes crucial (Belyea and Malmer, 2004). Most biogeochemical models of OM decomposition are derived from studies of mineral soils which contain moderate to low OM stocks, while so far there are comparatively few available data on peatlands despite their acknowledged role as highly efficient global C stores and sinks. This great potential for C accumulation in peatlands is due to low rates of plant residue decomposition (Thormann *et al.*, 1999). In such water-saturated ecosystems decomposition slows down, due in particular to oxygen limitation resulting from flooding which inhibits microbial and enzymatic activities. This leads to a high preservation rate of plant-derived biopolymers including those known to be rapidly consumed in soils (Pancost *et al.*, 2002), i.e. polysaccharides (Comont *et al.*, 2006; Laggoun-Défarge *et al.*, 2008). In addition to this high OM preservation, ombrotrophic peatlands are of great interest for climate studies since they are hydrologically independent of groundwater (Laiho, 2006) and, consequently their substrate moisture levels are directly related to atmospheric conditions.

Recently, in a review published in Nature, Davidson and Janssens (2006) concluded with the following: "*Regardless of the experimental and modelling approaches used, the debate about the temperature sensitivity of decomposition should be broadened beyond upland mineral soils specifically to include wetlands, peatlands and permafrost soils. These are the most obvious environments in which current constraints on decomposition are likely to change as a result of climatic disruption, thus potentially exposing large stocks of C to less constrained decomposition during the next few decades. A high research priority should be how the constraints to decomposition in these environments are sensitive to climate*". Along these lines, several approaches have attempted to assess the effect of warming on ecosystems: mesocosms, latitudinal transects, and *in situ* field experimental warming. Most of these studies assessed the warming impact on the functioning of ecosystems mainly through the responses of vegetation and surface gas emissions (e.g. Updegraff *et al.*, 2001; Aerts *et al.*, 2004; Strack *et al.*, 2006). To our knowledge, no study to date has addressed the entire range of effects of increased temperature on *Sphagnum* peatlands, including responses of biodiversity, community structure (plants, microbes and macrofauna) and ecosystem function (primary production, decomposition, C balance, microbial loop and trophic interactions). There is therefore an urgent need to understand the link between these key-compartments in peatlands, particularly in relation to C cycling in the face of global change.

Within the PEATWARM project, our aim is therefore to experimentally increase the temperature of a pristine mire from a temperate zone and to assess how the ecosystem is affected in its structure and function. The underlying idea is to determine to what extent a moderate temperature rise can modify the C sink function of peatlands in temperate regions.

The specific focus of the project is to determine how the temperature increase affects:

(1) the major plant functional groups
(2) the balance of above- and below-ground C fluxes (especially by the isotopic signature of respired CO_2)
(3) the microbial diversity and activity in *Sphagnum* mosses and in below-ground peat
(4) the dynamics of labile and recalcitrant OM of belowground peat.
(5) the interactions between plants-microbes-macrofauna in terms of C, N, S tranferts

The ultimate objective is the creation of a biogeochemical model of C coupled with N and S cycles that attempts to extrapolate changes to the system over the next two decades.

We propose to test the following hypotheses:

- A rise in temperature induces changes in primary net plant production, microbial growth, and microbial activity at the surface and in the belowground peat, thus resulting in a modification of the carbon balance;
- A temperature increase changes the structure of plant and microbial community structure, diversity and biomass, but responses vary among the taxonomic and functional groups;
- In response to rising temperature, the pool of stored OM, i.e. plant-derived biopolymers, decreases and is related to biotic factors (microbial activity) and abiotic parameters, e.g. moisture.
- The responses in community structure, biodiversity and OM composition can be used, alone or in combination, 1) as indicators of temperature-induced changes in the functioning of the ecosystem, 2) to reconstruct climate changes during the last 2000 years and 3) to predict future effects of climate changes.

We will implement 6 work-packages to answer to these hypotheses:

1. Modelling changes of temperature and humidity in peat as a function of air temperature in the OTCs. Analysis of the influence of plant cover and modifications of vegetation.
2. Determination of the impact of warming on the abundance, diversity and structure of microbial communities at the surface and at below-ground peat.
3. Evaluation of CO_2, CH_4 and N_2O fluxes in the peatland surface as a function of temperature. Identification of the origin of respired CO_2 by the ^{13}C analysis.
4. Determination of the effect of warming on organic matter dynamics in the peat substrate, in particular by the identification of carbon isotope signatures in individual water soluble organic compounds, i.e. monosaccharides, amino-acids and phenols.
5. Identification and calibration of the most relevant warming proxies. The patterns in the peat records of the identified proxies will be used to reconstruct palaeotemperature evolution during the last 2000 years.
6. Creation of a biogeochemical model of carbon, including the response to temperature disturbance of the different above-mentioned compartments. The preparation of a more "complex" model of C-N-S emissions will also be attempted. The study of biotic interactions C-N-S transfers will be conducted by ^{13}C-^{15}N-^{34}S triple labelling.

Study site and methods

The study is performed on Frasne peatland (46°49'N, 6°10'E), an undisturbed *Sphagnum*-dominated mire situated in the Jura Mountains (France). The site is protected by the EU Habitat Directive of Natura 2000 and has been classified as a Regional Natural Reserve for more than 20 years. At this site, annual precipitation amounts to 1300-1500 mm per year with a mean annual temperature of 7-8°C. The two studied sites of the peatbog (see below) have a moss cover of 85-95% while the cover of herbaceous plants is about 60%. The moss component in these two sites is dominated by *Sphagnum magellanicum, S. fallax, S. warnstorfii,*. The vascular plants mainly consist of *Eriophorum vaginatum, Scheuchzeria palustris, Andromeda polifolia, Vaccinium oxycoccos and Carex limosa*. Among shrub species, *Calluna vulgaris* also occurs. (Bailly, 2005).

The warming device consists in the use of *in situ* fibreglass Open-Top Chambers (OTCs) based on a standardised protocol from the ITEX (International Tundra Experiment) systems. ITEX is a scientific network of experiments focusing on the impact of climate change mainly on high-latitude ecosystems (e.g. Marion *et al.*, 1997; Arft *et al.*, 1999). The OTCs are made of transparent hexagonal polycarbonate chambers (50 cm high and 1.6-1.8 m in diameter at the top and 2.2-2.5 m at the base). They have particularly been used to study phenological changes of specific plant species to climate change in arctic and subarctic areas (Aerts *et al.*, 2004). The climate scenario we have imposed on the vegetation and the below-ground peat within the OTC plots is a temperature rise of 1 to 3°C representative of future climate scenarios in the study region (IPCC, 2007). Two model functional groups are being considered in order to assess the community-level interactions and ecosystem responses to global warming: (1) a transitional *Sphagnum*-dominated poor fen site and (2) an open bog site with mixed vegetation (*Sphagnum* spp., *Eriophorum* and other vascular plants, e.g. *Andromeda polifolia*). In each of the two sites, 12 randomised plots have been chosen (6 controls and 6 OTCs). We will monitor the abiotic environmental parameters (air and soil temperature, water table depth, pH). Beside the field study, experiments in climate chambers under controlled laboratory conditions (temperature, humidity and nutrients) will also be carried out to test threshold effects.

Conclusion and perspectives

Within PEATWARM, the short-term (i.e. 4 years) experiments can be expected to show the effects of warming first on the labile pool of soil organic carbon, i.e. hydrosoluble compounds. These effects may not, however, elucidate the long-term change in ecosystem functioning (Knorr *et al.,* 2005). Therefore, beyond the duration of PEATWARM project, we plan to maintain the warming devices (OTCs) in the site for at least the next two decades in order to monitor *long-term* controls of peatland C turnover in the face of global change. With the same aim in view, we are initiating a French network for research related to "Global Warming and Peatlands". The goals are (i) to develop integrated and inter-disciplinary research within one or a few instrumented sites (ii) to gather data and build a common database for sharing knowledge and experience and (iii) to transfer this knowledge to managers and peatland-owners. The peatland of Frasne will be proposed as a pilot site for the network as the peatland is well equipped with monitoring devices.

Ultimately, our goal is to compare our data and model with those obtained on sites equipped with the same ITEX systems. To design suitable models for testing scenarios, a relevant comparison might be carried out with peatlands occurring at high latitudes, i.e. boreal and sub-arctic peatlands, where the effect of warming is expected to be more marked. Such cooperation could fruitfully be developed within a EU Network. The creation of a Network for European sustainable peatland management against the threat of global warming will contribute to the development of current and future legislation for the protection of these key ecosystems.

Acknowledgements

This paper is a contribution of the PEATWARM project (Effect of moderate warming on the functioning of the *Sphagnum* peatlands and their function as carbon sink) financially supported by the French National Agency for Research under the « Vulnerability : Environment – climate » program (ANR-07-VUL-010) for 4 years (2008 – 2011). The Regional Scientific Council of Natural Heritage of Franche Comté gave permission to perform these experiments in the Regional Natural Reserve of Frasne. We gratefully acknowledge Geneviève Magnon (Communauté de Communes Frasne - Drugeon) for her help in obtaining permission to the site access.

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